

TERRESTRIAL KILOMETRIC RADIATION AND MAGNETOSPHERIC ACTIVITY: BURSTS AND SUBSTORMS, PERIODIC EMISSIONS AND FIELD-LINE RESONANCES

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Abstract

We show that several classes of AKR emissions can be distinguished. Two of them are presented here: AKR bursts, isolated emissions suddenly excited over a large frequency range, and periodic pulsations of the AKR emissions. They are associated to well defined magnetospheric processes: the onset of the expansion phase of magnetospheric substorms for the bursts, global oscillations or resonances of magnetic field-lines for the pulsations. We stress the potential they contain for remote observation of magnetosphere dynamics.

1 Introduction

Until now, the Auroral Kilometric Radiation has mainly been studied for itself. Most of the efforts have been made for understanding the microscopic processes responsible for the generation mechanism and the radiation pattern. Several attempts have been made to connect the source regions of the radiation to auroral features, it has been shown that these sources were located on magnetic field-lines threading auroral arcs. This has been made either with the association of ray-tracing and observations [Huff et al., 1988] and directly, when the spacecraft (Viking) crossed the radiation sources [de Feraudy et al., 1988]. Several attempts have been made to relate the AKR to the auroral activity, among them, Voots et al. [1977], Kaiser and Alexander [1977b], Benson and Akasofu [1984], more recently AKR emissions have been correlated to electron precipitation [Imhof et al., 1998]. In all these studies the AKR was an undifferentiated object.

In this paper we shall show that behind the generic name "AKR" one can distinguish several classes with well defined morphological characteristics. We shall relate these classes

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to dynamical magnetospheric processes. In that way bursts of AKR are identified and related to the onset of a substorm expansion phase; periodic pulsation of the AKR emissions are put in evidence and related to the so-called Pc5 periodic pulsations of the Earth magnetic field-line (for geomagnetic micropulsations see Jacobs et al. [1964]), or to the magnetic field-line resonance phenomenon (e.g. see Samson and Rankin [1994]). A consequence is that the AKR, and similar planetary radio-emissions are powerful tools for the remote observation of the planetary magnetospheres.

2 The wave instrument

The wave observations are made with POLRAD, the high frequency wave experiment of the auroral probe of the Interball mission [Hanasz et al., 1998]. POLRAD is a super-heterodyne radio receiver which analyses two frequency ranges: 4 kHz - 1 MHz or 4 kHz - 500 kHz, step by step, through a 4 kHz bandwidth filter. Depending on the operating mode, the duration of the analysis for each frequency step is 25 ms or 50 ms so that a full spectrum is scanned in 6 or 12 s, with a frequency resolution of 4 kHz. Thus, the output of each individual frequency step is nothing else than a power density. The sum of all the power densities over the frequency range of the AKR is referred to as "AKR intensity".

3 AKR radio-bursts and substorms

AKR radio-bursts consist of isolated impulsive emissions with a large bandwidth, typically 100 kHz - 800 kHz, which is usually broader than any other manifestation of AKR. The whole frequency range is excited at once, in a short rising time, typically 2 or 3 minutes. Then follows a relaxation phase where the bandwidth shrinks. Several such bursts are shown in Figure 1A. In order to estimate the rise time and the exponential relaxation of the bursts, we have used the variations with time of the event (Figure 1B). One sees that actually 4 bursts were emitted, the first two overlapping. The frequency scale is logarithmic, therefore the quasi-rectilinear negative slopes are equivalent to exponential decays. The two major events decayed in about 10 minutes. This relaxation is not interpreted, however, quite likely it reflects the exponential decay of some process occurring along the source field-lines. The altitude range of the burst sources, deduced from the values of upper and lower frequencies is commonly 2000 km - 20000 km.

Similar observations are frequent. Their features are not the result of the specific geometry of some emission cone, which is familiar in similar radio-emissions from other planets, with a spacecraft entering or getting out of the cone. This is clearly illustrated in Figure 2, which present the same bursts observed at the same time by two distant spacecraft: POLAR (upper panel) and Interball (lower panel). The two s/c were at quite different altitudes: 8 Earth radii (R_E) for POLAR, less than 4 R_E for Interball, with different Magnetic Local Time (MLT) ranges.

It has been shown that the AKR bursts are triggered at the beginning of the expansion phase of substorms [Hanasz et al., 2001]. This has been deduced from the examination of

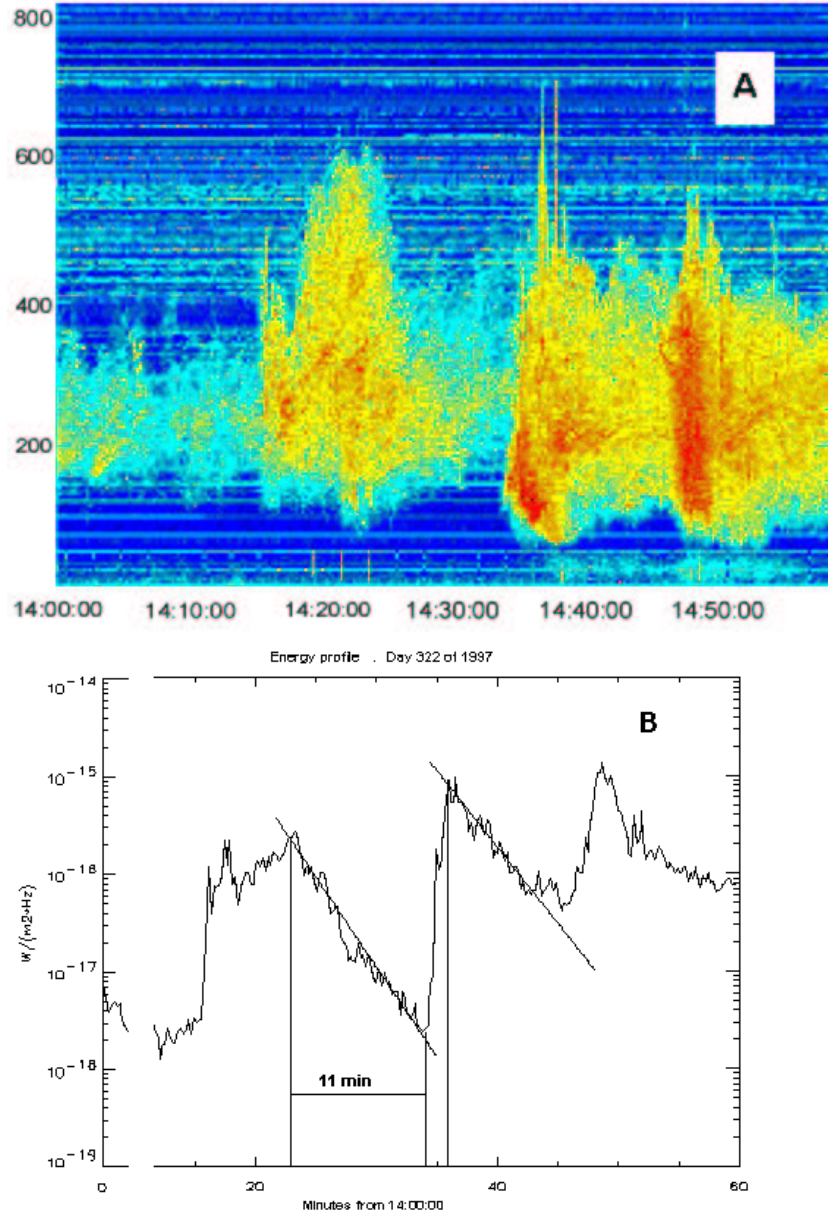


Figure 1: A) Spectrogram of AKR bursts. They are isolated events, partially overlapped. B) Intensity of the bursts versus time. The vertical axis is in logarithmic scale. The exponential decay of the bursts is clear from the linear shape of the curve. Straight lines are drawn in order to stress this feature. The vertical lines show the 2 characteristic times: 2 min for the rise time, 10 min for the decay.

16 cases, when simultaneous observations of AKR bursts from POLRAD and UV images from UVI, the UV imager of POLAR, were available. The auroral signature of a substorm expansion phase is the rapid poleward expansion of a bulge in the auroral UV emissions, in

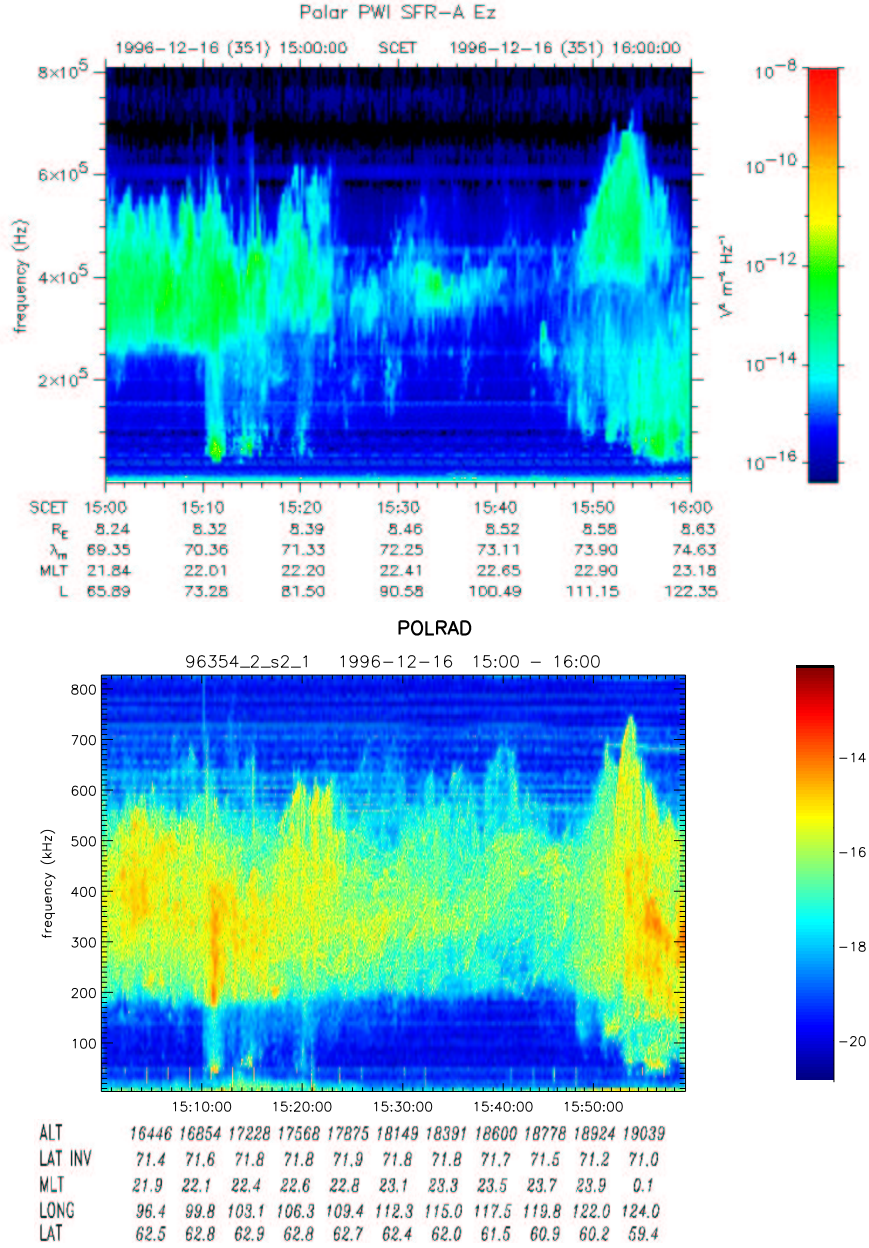


Figure 2: Spectrogram of bursts overlying more diffuse AKR emissions. The same event is observed from POLAR (top panel) and from Interball (bottom panel). Note the strong similarity of the burst observations. The 15:10:40 UT burst is the same as in Figure 3.

the midnight MLT sector. The intensity of the AKR had been correlated to the intensity of the brightest pixels of the auroral bulge images. In all the examined cases the bursts were triggered few minutes after the rise time of the brightest spot of the bulge intensity [see Figure 5 of Hanasz et al., 2001]. One possible process for the auroral bulge development

is the onset of a current wedge associated to the onset of a field aligned current system. Then, the correlation between the bursts and the auroral bulge development should be the macroscopic counterpart of the association of AKR activity to auroral precipitation. If the interpretation holds, the delay between the bulge development and the AKR bursts triggering can be the consequence of some threshold in the field aligned currents - or in the fluxes of precipitating electrons - below which the AKR could not be generated.

This is illustrated in Figure 3 which shows the auroral pattern, observed with UVI, before, during and after the burst observed at 15:12 MLT on Figure 2. The overall auroral pattern is stable while an auroral bulge is rapidly developing around 22:00 MLT. The cross shows the footprint of the magnetic field-line passing through Interball.

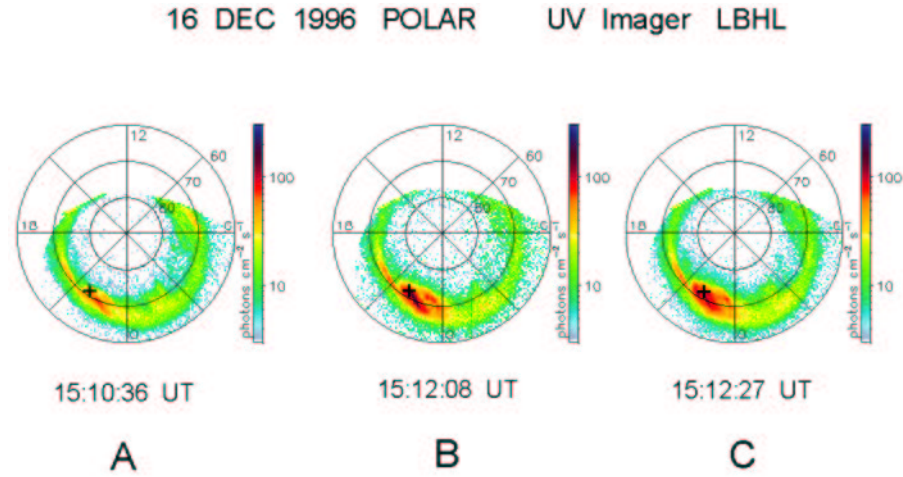


Figure 3: Sequences of UV images of the polar cap for the 15:12 UT burst of Figure 2. The bulge, observed at 70° Magnetic latitude, 22:00 MLT, rapidly expands. The AKR burst is triggered at the onset of the red bright spot. The cross is the field-line footprint of the s/c.

4 Periodic AKR emissions, micropulsations and field-line resonances

In many occasions the AKR emissions are periodically modulated or triggered. Sequences of 3 to 10 nearly periodic patches of AKR emissions have been observed. This is illustrated in Figure 4, which shows a periodic sequence of 7 AKR patches. The intensity curve of the event is superposed to the spectrogram (logarithmic scale). The bottom panel of the figure is the result of a spectral analysis of the event. The frequency of the patch occurrence is calculated with the Lomb periodogram method [Horne and Baliunas, 1986]. 115 well defined observations from POLRAD of periodic pulses have been selected for analysis.

The major frequency peak is around 1.9 mHz, which is in the range of the so-called Pc5 micro-pulsations. Statistics made on the AKR pulsation frequencies confirm this observation: all the observations are pulsated at frequencies below 5.5 mHz. The histogram

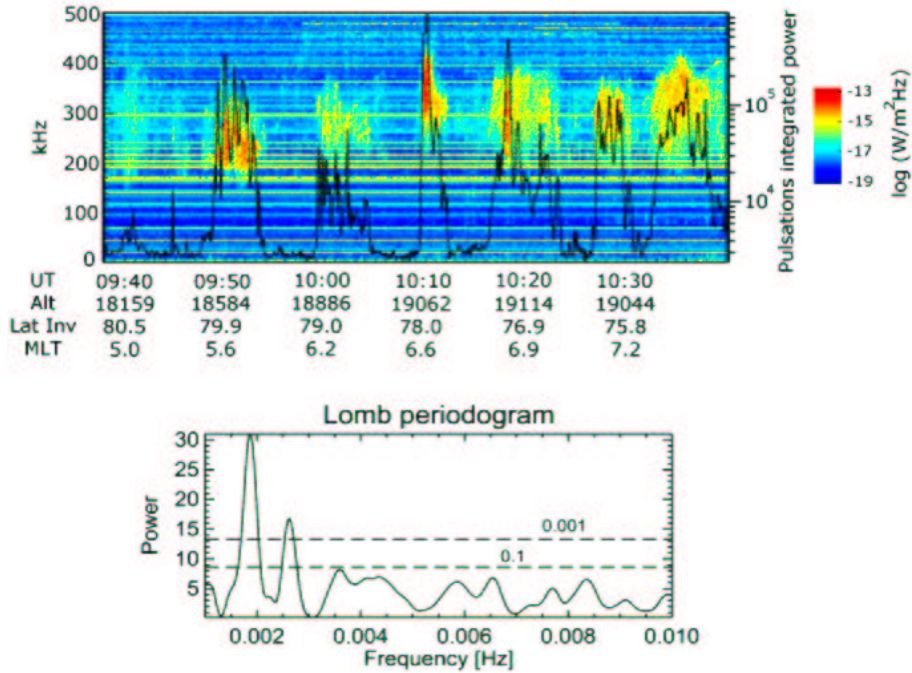


Figure 4: Sequence of 7 periodic pulsations of AKR. The overlaid line on the spectrogram is the AKR intensity. Bottom panel: spectral analysis of the intensity line. The dominant periodicity is 1.9 mHz.

is shown in Figure 5. The grey boxes are 0.5 mHz wide. This width has been chosen in order to grant statistical significance of the histogram. The greatest occurrence is at 1.3 mHz. Therefore the AKR emissions are likely modulated by pulsations of the Earth’s magnetic field-lines.

The Pc5 micro-pulsations are global oscillations of the Earth’s magnetic field-lines. Their frequency range is also the one of the Field Line Resonances - FLRs [Samson, 1972; Harold and Samson, 1992]. These resonances have a fairly stable discrete set of frequencies, weakly dependent on the magnetospheric conditions and on the latitude as well. Their average values, calculated from oscillation of ground-based magnetograms are 1.3, 1.9, 2.6, 3.4, 4.3 mHz. These values are indicated on Figure 5, they are inside the frequency distribution of the AKR pulsations. In order to determine whether the AKR pulsations are to be associated to FLRs or not, we have split the main boxes of the histogram in two sub-boxes (white boxes in Figure 5), with a loss of significance. Clearly the figure shows that the peaks of the AKR pulsation frequencies are at those of the FLRs. Besides, the analysis of the MLT distribution of the Interball observations (not shown here) presents similarities to the one of the FLRs: two maxima of occurrence, one in the morning sector, one around midnight. Thus, the observations strongly suggest that a large part of the AKR pulsated emission or generation processes are produced by FLRs.

The mechanisms for this modulation are not known, however FLRs provide good conditions for it. Pc5, like FLRs, are Alfvén waves. It has been shown that they evolve non

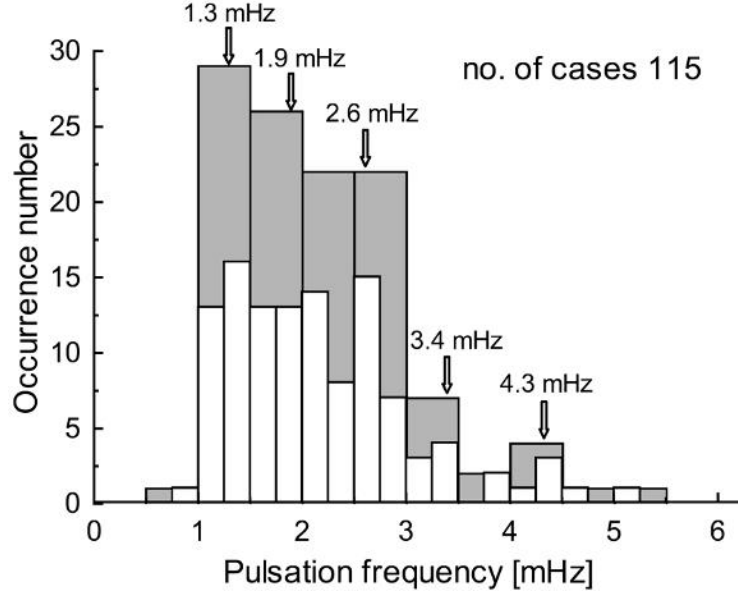


Figure 5: Histogram of the frequencies of 115 pulsations. The width of the gray bins has been halved (white bins), with a less significant number of events inside, in order to show the similarity of the AKR pulsation frequencies with those of the FLRs.

linearly to smaller and smaller scales, transverse to the magnetic field-lines, down to the inertial or kinetic scales. These scales are in good agreement with the order of magnitude for AKR source sizes. In addition, inertial or kinetic Alfvén waves generate parallel wave electric fields with potential drops reaching several keV [Goertz, 1984]. This is in agreement with the correlation of AKR with strong keV electron fluxes. When the non linear wave fields are strong enough, and when the electromagnetic structures are well confined transversally to the magnetic field, a ponderomotive force is generated at their edges. Its effects are the sharpening of these edges and the production of strong oscillations of the plasma pressure at the FLR frequency [Voronkov et al., 1997]. This should contribute to the periodic formation of the plasma cavities which are necessary for the AKR sources.

5 Conclusion

AKR is a generic name for a variety of radio-emissions. Their common denominator is their mode of production which is very likely the maser synchrotron mechanism. Their differences appear on the morphology of their spectral characteristics and on their time evolution. These two features depend on the source size and on its time evolution which are controlled by external parameters such as the energy of precipitation particles, their fluxes, the existence of strong fluctuation of the plasma and magnetic field parameters.

We have identified two such varieties: bursts of AKR and periodic fluctuations or periodic generation. Each has been associated to large scale magnetospheric processes: the starting

of substorm expansion phase, field-line oscillations or resonances. This shows that the AKR, or similar radio-emissions, in spite of many unknowns on the conditions necessary for their generation, contain a great potential for remote observation of the magnetosphere dynamics. The frequency range of the AKR indicate the altitude range where the field-lines are active. For instance the time constants, such are the rise time or the decay time of the bursts, are indicative of the underlying magnetospheric processes.

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